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Dynamic Management of Prescribed Burning for Better Air Quality

RD-83521701

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Georgia Institute of Technology

EPA STAR "Dynamic Air Quality Management" Kick-Off
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Problem Statement

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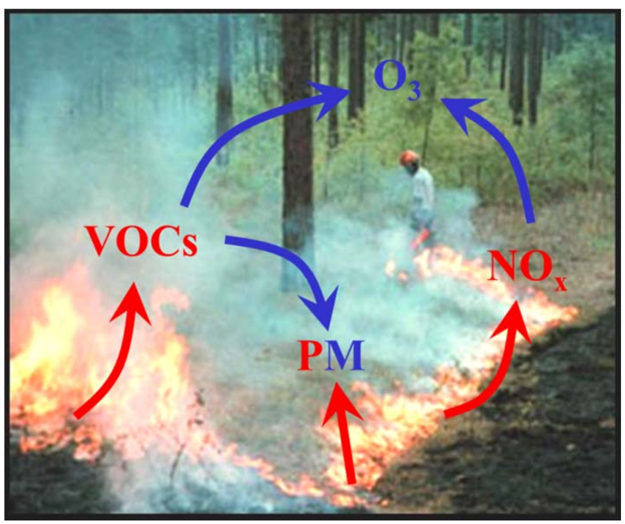
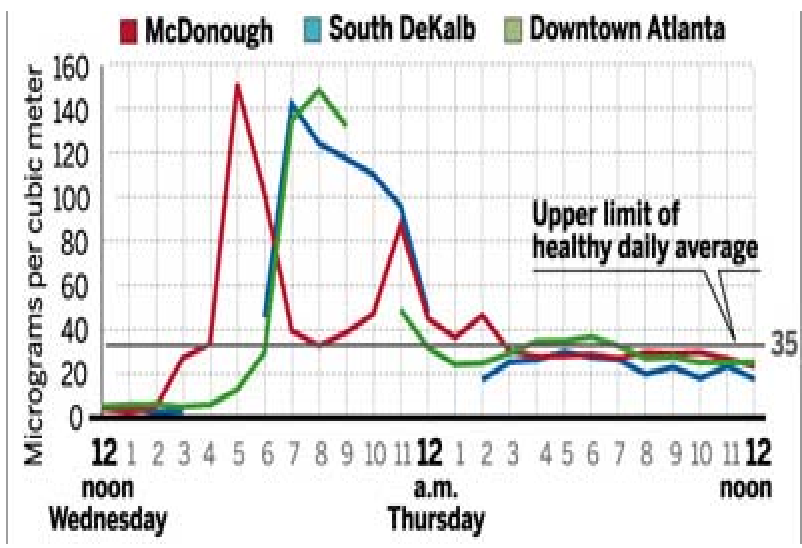
- One of the most promising emission sources to address through dynamic management is prescribed burning (PB).
- PB is required for important ecological and safety concerns. 8 million acres of land in the Southeastern U.S. and 1 million acres in Georgia are treated with PB.
- PB is listed as the 3rd largest source of $PM_{2.5}$ emissions nationwide accounting for 12% of the total. This rank is expected to go up in the future.
- PB can significantly impact air quality (AQ) in neighboring urban areas, contributing both to primary and secondary $PM_{2.5}$ as well as to O_3.
- Ecological reliance on PB combined with increased AQ pressure due to tighter regulatory constraints necessitates better management of PB operations.





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Technical Objective

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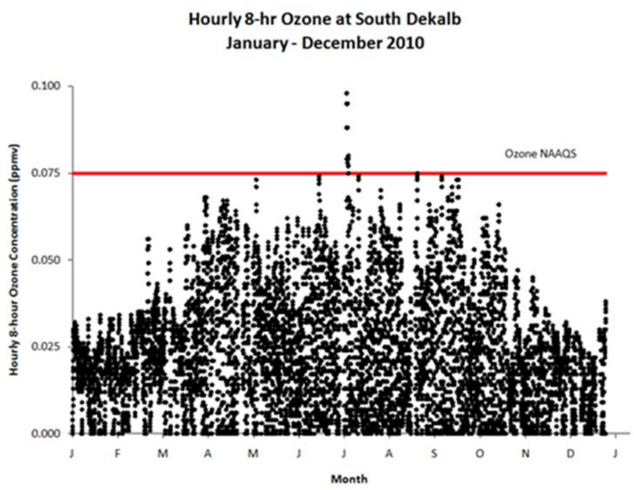
• To develop a dynamic AQ/PB management system that can not only moderate the potential impacts of PB on AQ, but also moderate AQ constraints that now limit PB.

- Develop an AQ impact prediction system for the impacts of PB
- Evaluate the forecasting accuracy of the system
- Investigate how the system could be used in operational capacity
- Assess the benefits of the system in AQ and PB management.



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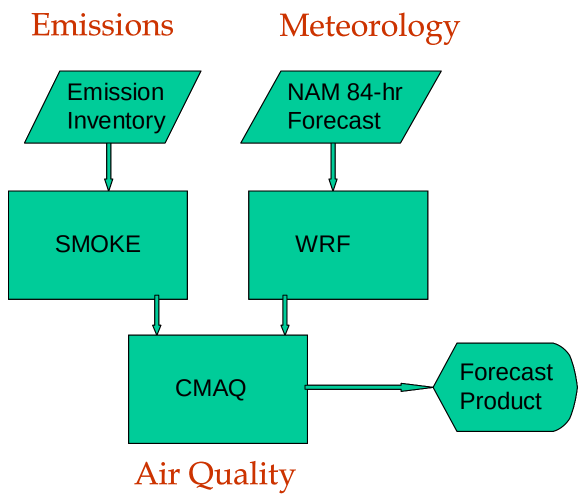
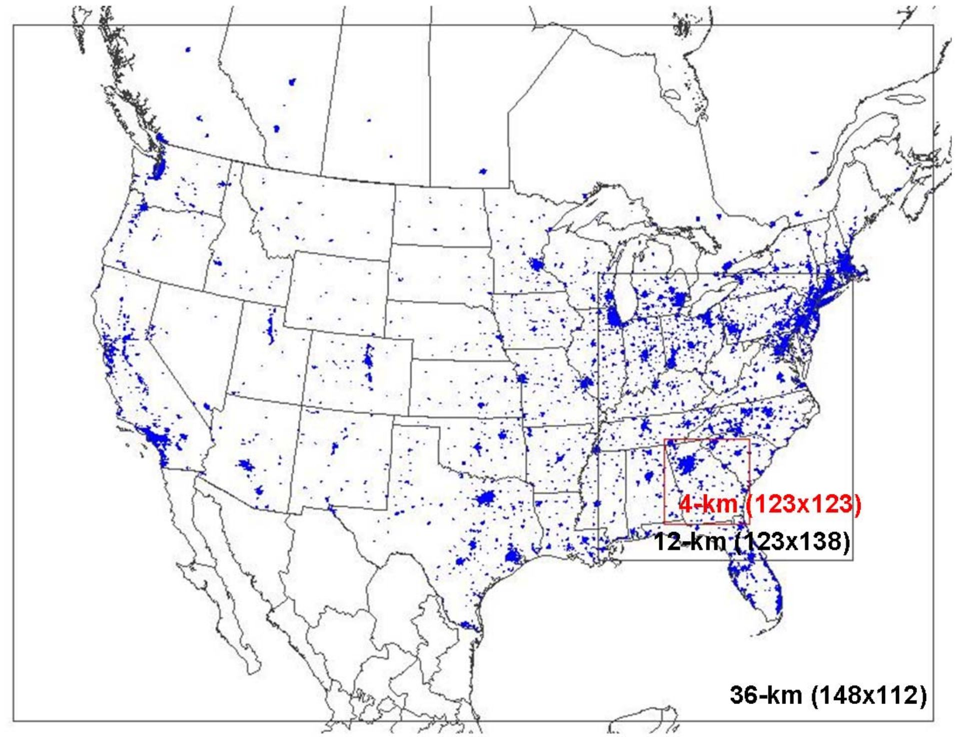
Hi-Res: forecasting ozone and $PM_{2.5}$ at a 4-km resolution for metro areas in Georgia

Hi-Res Air Quality Forecasting System

Serving Metro-Atlanta Area since 2006



Hi-Res Modeling Domains



Hi-Res Cycle

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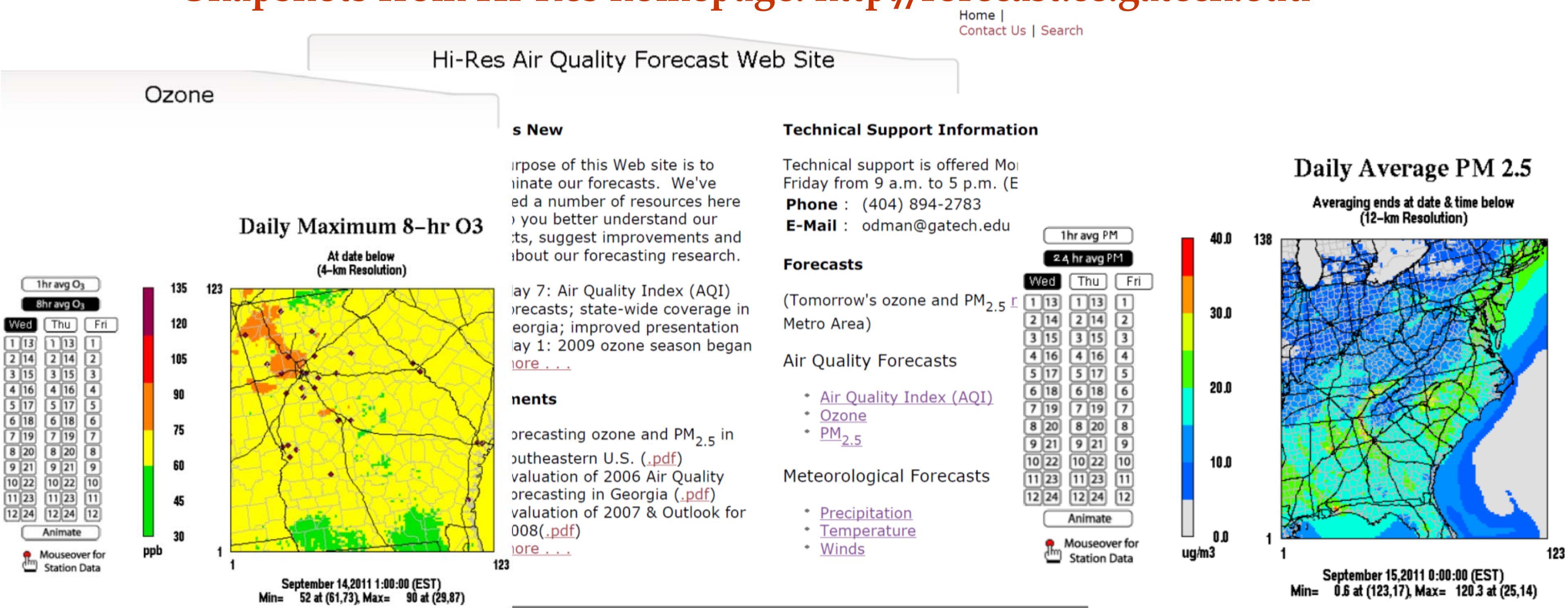
Hi-Res Forecast Products

- "Single Value" Report: tomorrow's AQI, ozone and $PM_{2.5}$ by metro area in Georgia
- Air Quality Forecasts: AQI, ozone and $PM_{2.5}$, 48-hrs spatial plots and station profiles
- Meteorological Forecasts: precipitation, temperature and winds, 48-hrs spatial plots and station profiles
- Performance Evaluation: time series comparison and scatter plots for the previous day

Snapshots from Hi-Res homepage: http://forecast.ce.gatech.edu



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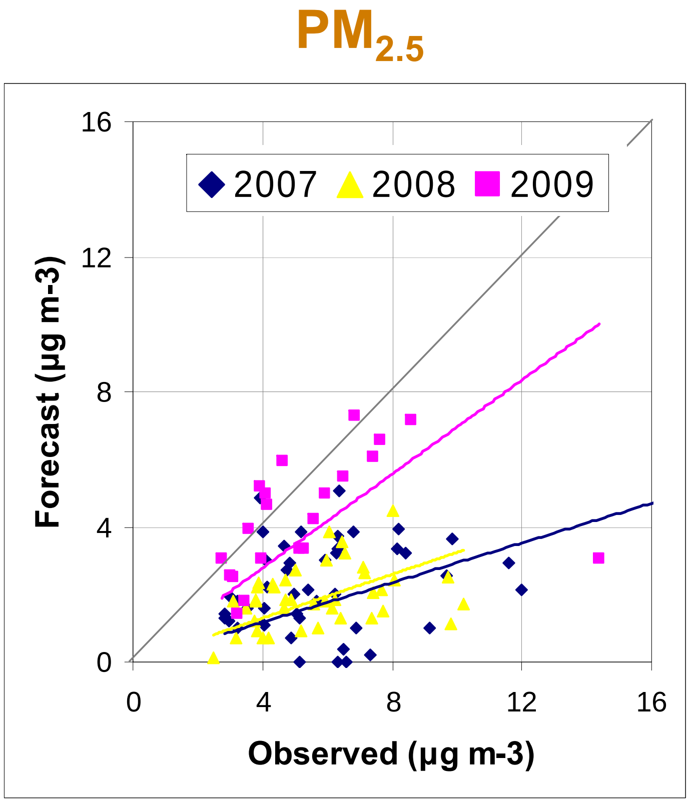
A New Model for SOA (Baek et al., 2011)

Included processes:

- SOA partitioned from oxidation of VOCs (8 SVOCs)
- From monoterpenes (2 SVOCs)
- From isoprene (2 SVOCs added)
- From sesquiterpenes (1 SVOC added, gas phase oxidation reactions added for α-caryphyllene, β-humulene, and other sesquiterpenes)
- Aging of all semi-volatile organic compounds (SVOCs) added

$$\text{HSVOC} \xrightarrow{+OH,+O3} \text{LSVOC} \xrightarrow{+OH,+O3} \text{SOA}$$



In 2009, $PM_{2.5}$ forecasts improved primarily due to the new SOA model.

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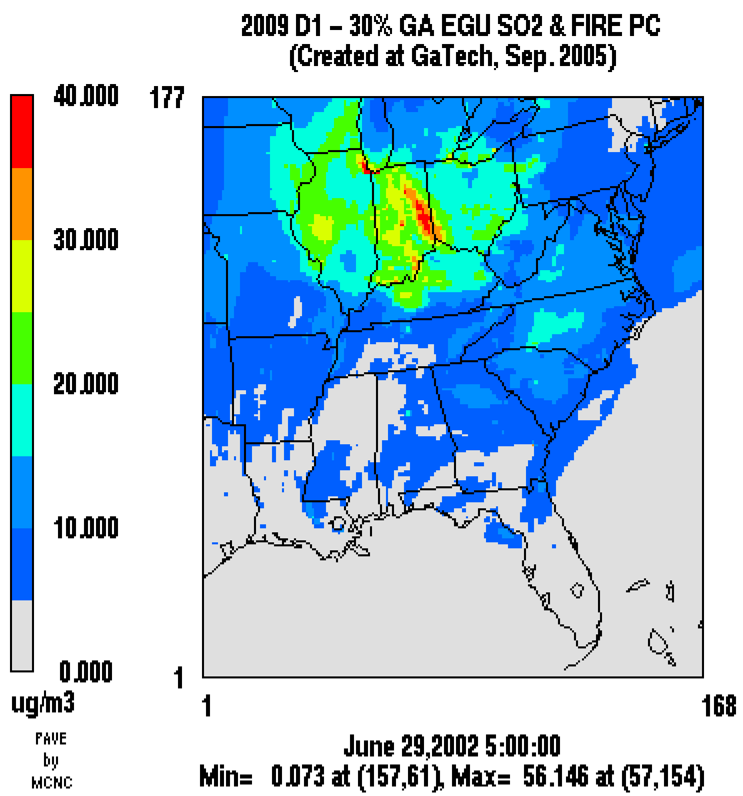
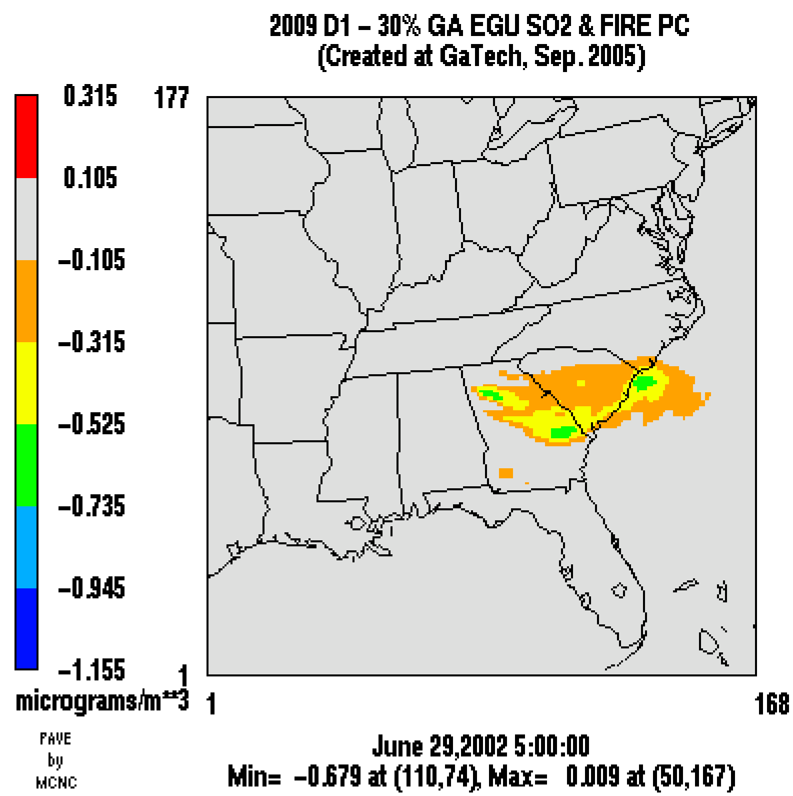
Forecasting Capabilities

- In addition to concentrations we can forecast impacts of specific emission sources.

Daily Average PM 2.5



PM2.5 Response



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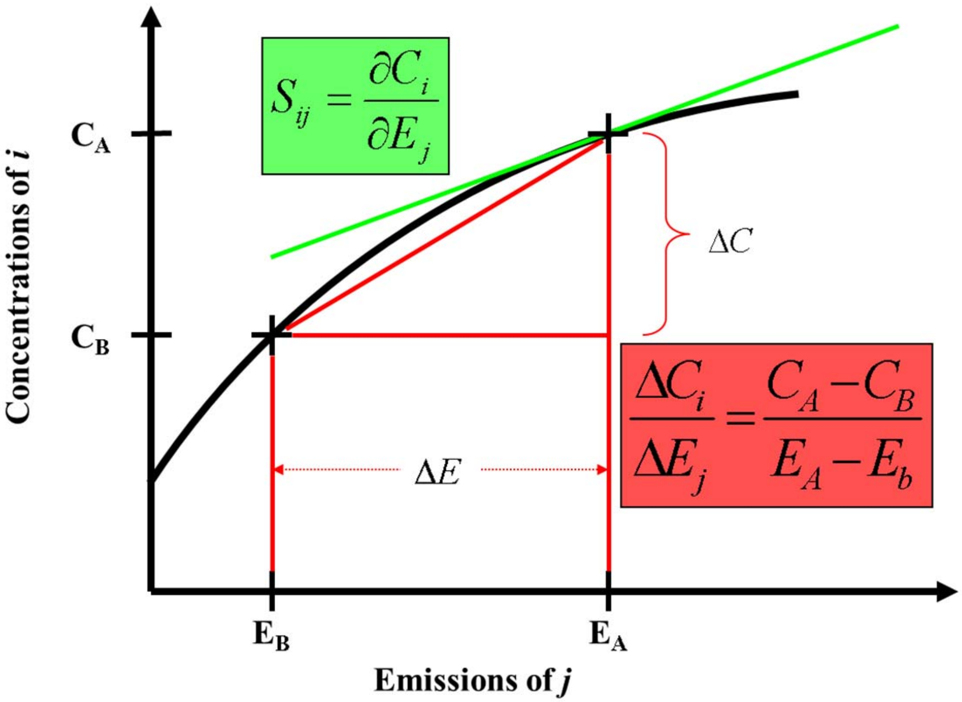
Sensitivity vs. Response

- Sensitivity is the change in pollutant concentration due to change in some parameter of interest (e.g., emissions).

$$S_{ij}^{(1)}(x,t) = \frac{\partial C_i(x,t)}{\partial p_j}$$

- Response can be approximated as:

$$\Delta C_i \approx S_{ij}^{(1)} \Delta p_j$$



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DDM-3D in CMAQ

- Community Multiscale Air Quality Model (CMAQ) solves the Atmospheric Diffusion Equation (ADE)
- Sensitivity equations were derived by taking the derivatives of ADE

$$\frac{\partial C_i}{\partial t} = -\nabla(uC_i) + \nabla(K\nabla C_i) + R_i + E_i$$

Advection Diffusion Chemistry Emissions

$$\frac{\partial S_{i,j}}{\partial t} = -\nabla(uS_i)_j + \nabla(K\nabla S_i)_j + JS_{i,j} + \delta_{i,k}$$

- DDM solves the sensitivity equations simultaneously
- There are computational savings due to similarity of the equations

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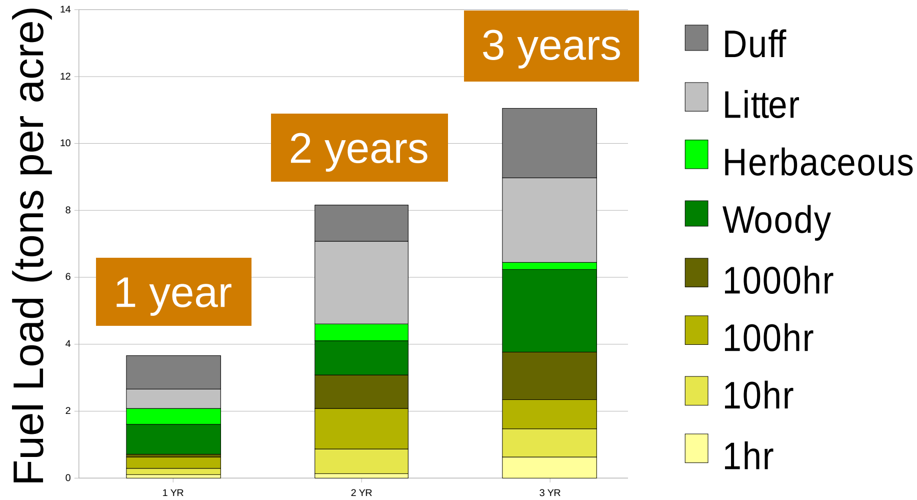
Estimation of PB Emissions



- CONSUME 3.0 calculates the amount of fuel consumption under different fire conditions.
- Emission Factors (EF) are available from field and/or laboratory studies.
- Emissions = Consumption × EF

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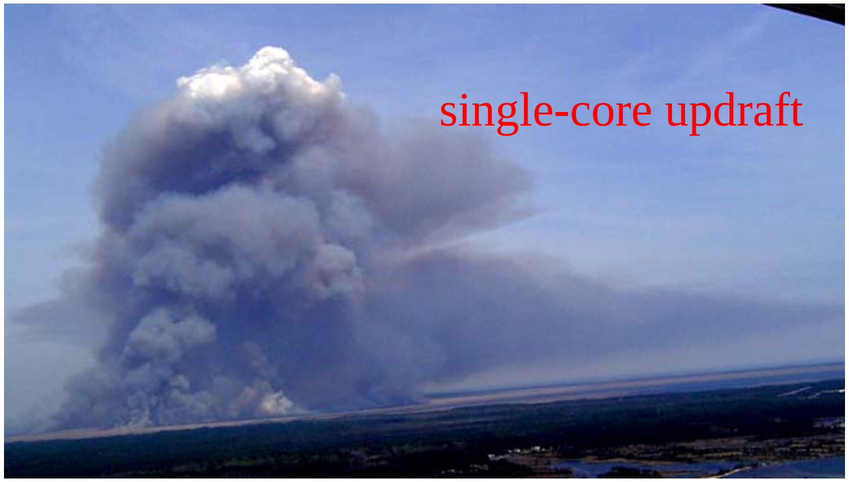
Prescribed Burn Plumes

• PB plumes cannot be simply characterized as ground-level sources, industrial stacks, or with any other simple plume rise algorithm.



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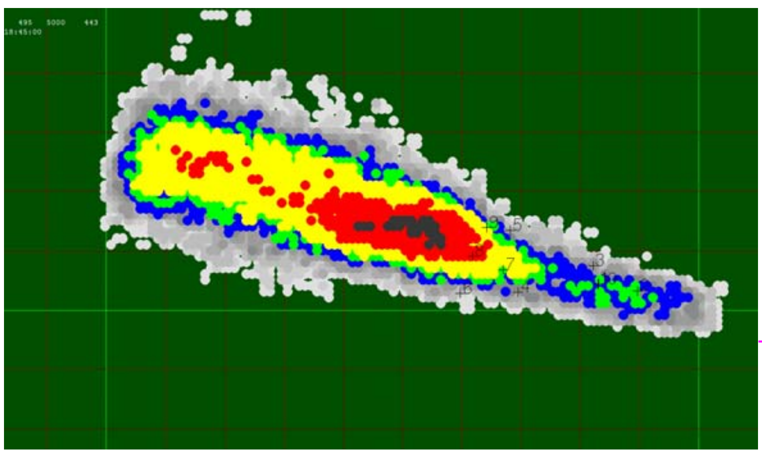
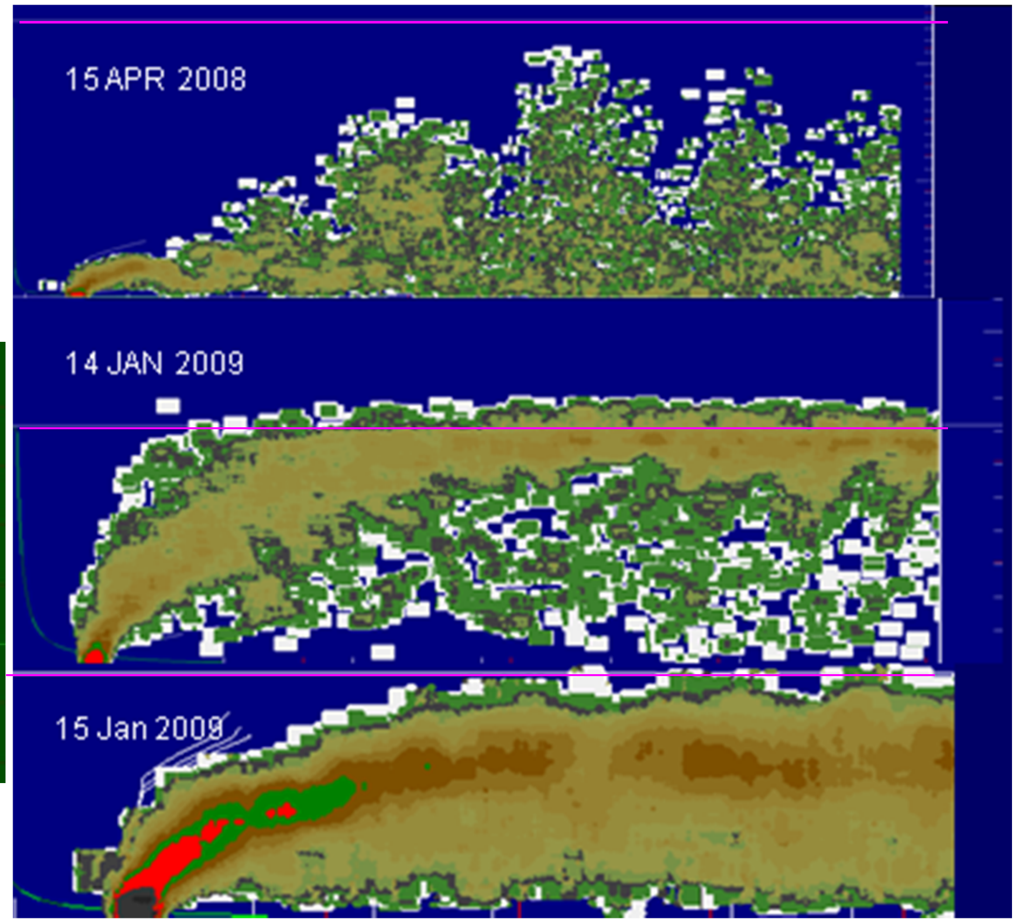
Daysmoke Plume Dispersion Model

- Daysmoke is an empirical plume rise/dispersion model designed for PB plumes.





- We use Daysmoke to inject PB plumes into CMAQ.

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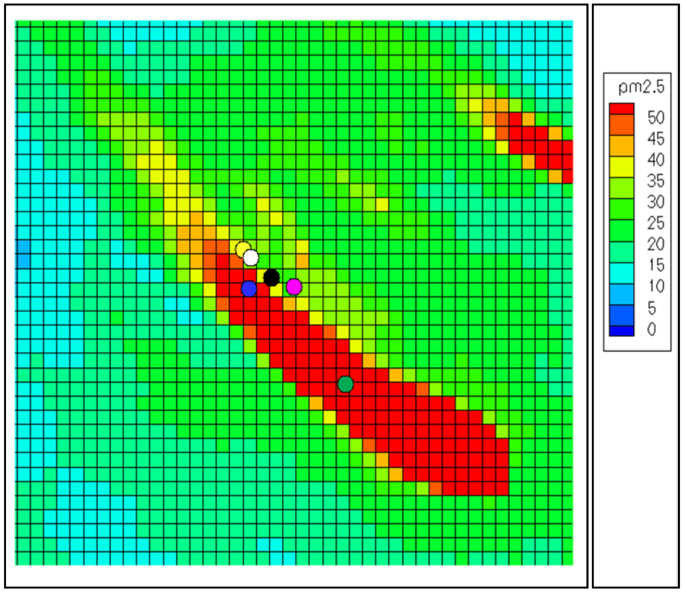
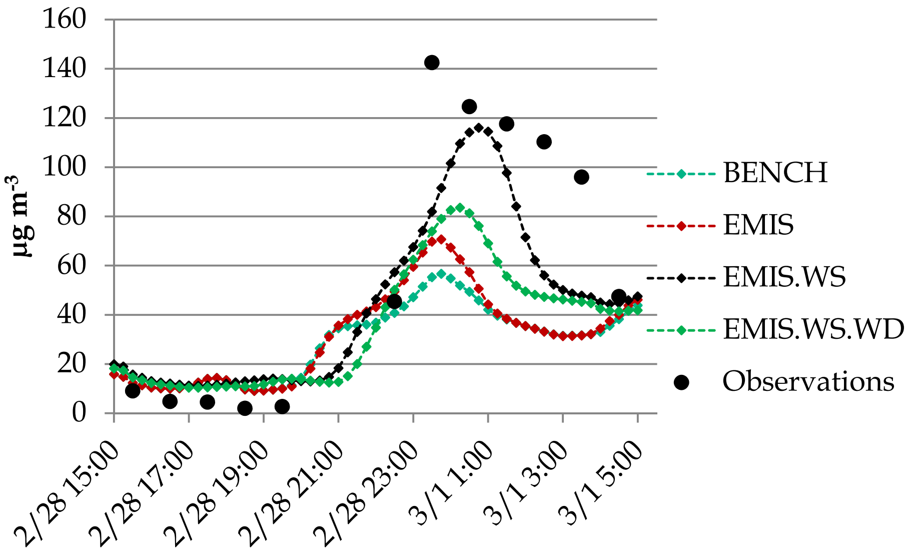
Diagnostic Evaluation of Models

Predicting regional smoke impacts depends on the ability to predict:

- Emissions (amount and timing)
- Injection height (plume vs. PBL)
- Winds (speed and direction)





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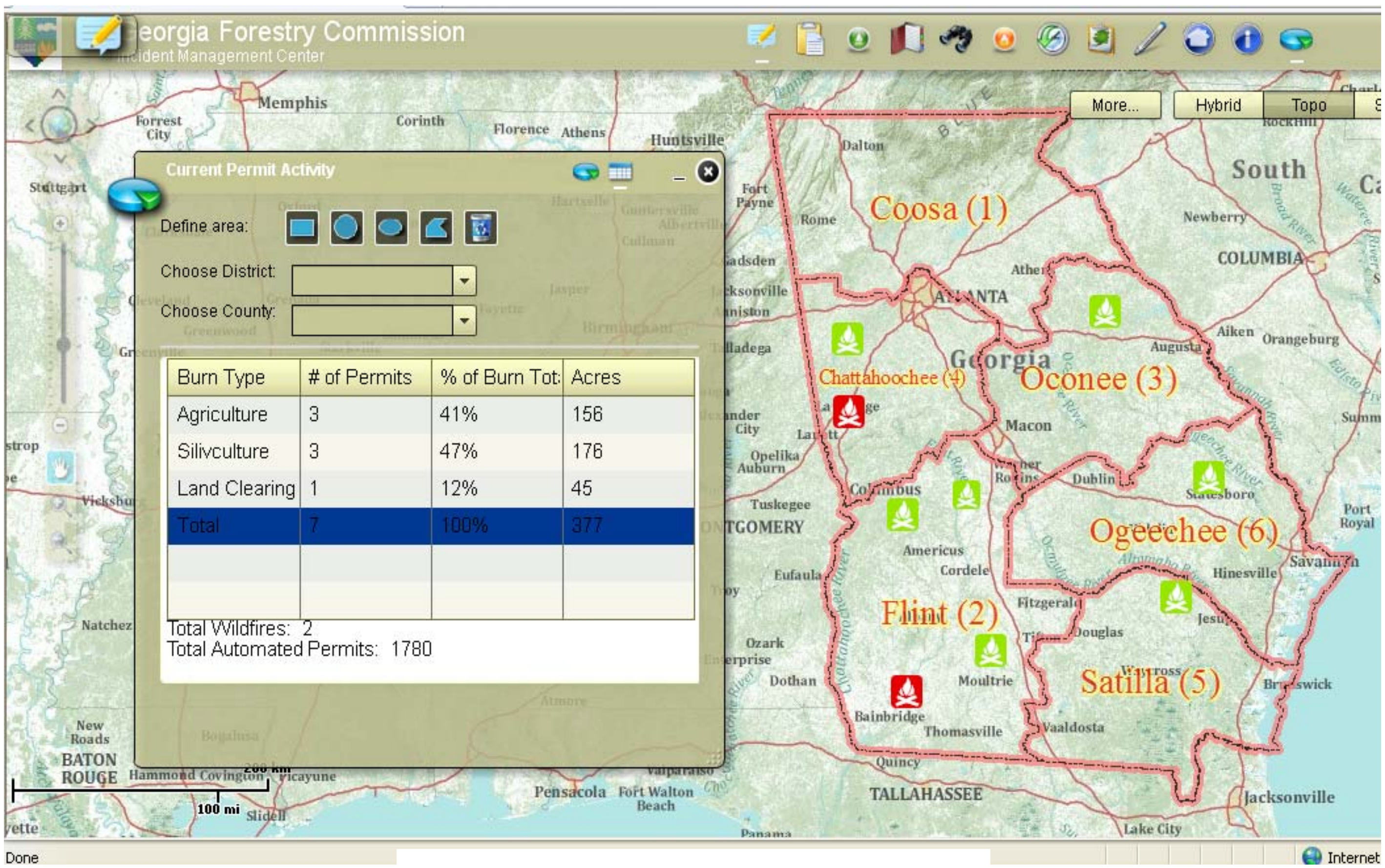
GFC Permit Tracking System

- Location, acreage, burn type, start and end times of PBs are stored and displayed for each issued permit.



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Technical Approach

Development of PB Impact Forecasting System

1. Burn permit database query
2. Emission estimation
3. AQ impact forecast
4. Interpretation of forecast

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Evaluation of PB Impact Forecasting System

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Investigation and Assessment of Management Options

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Permit Database Query

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Challenge: No a priori knowledge of who will burn next day

Approach:

- Search GFC burn permit database for submitted plans and previous burning patterns (frequency and last occurrence) to determine likely burners
- Extract location, acreage, fuel type and fuel load information for each potential burner
- Fuel loads can be estimated based on growth type and time since last burn. Alternatively, fuel loads can be obtained from:
  - National Fire Danger Rating System (NFDRS) fuel maps
  - Fuel Characteristic Classification System (FCCS) fuelbed maps
  - MODIS (Moderate Resolution Imaging Spectroradiometer) Normalized Difference Vegetation Index (NDVI) maps

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Emissions & AQ Impacts

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- Estimate fuel consumption using CONSUME 3.0
- Estimate emissions using EFs for southeastern fuels
- For large burns, use Fire Emissions Production Simulator (FEPS) to estimate hourly distribution of emissions
- Compute vertical distribution of emissions using Daysmoke
- Update Hi-Res forecasting system components
    - CMAQ 5.0 is available now
- Start forecasting impacts of PB emissions on $PM_{2.5}$ and O_3
    - DDM-3D (with 1st–order sensitivities) will be available soon
- Investigate if ~20 sensitivities can be computed simultaneously
    - emissions by fire district or pilot county
    - below/above PBL height

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Interpretation of Forecast

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- Impact forecast results will be in the form of change in air quality (e.g., ΔO_3 in ppm and $\Delta PM_{2.5}$ in μg m^{-3}) per ton of nominal PB emissions.
- To be useful in management, these results need to be converted from "per tons" to "per acres" at a particular location.
- Recall that emissions from all "likely-to-burn" lands in the same district or county were lumped together for the impact forecast. However, not all "acres" in that district or county are the same.
- Conversion must be made considering the spatial variation of all impact relevant factors such as fuel types, fuel loads, size of the burn, ignition method, etc.

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Evaluation of Forecasts

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- Look out for possible PB impacts at state monitors reporting elevated pollutant concentrations.
  - Use satellite products (text, imagery, and analysis) from NOAA Satellite and Info. Service as well as interactive fire location maps and plume trajectories from SMARTFIRE to confirm PB impact.
- Select some of these instances for case studies. Simulate each case with impact prediction system in a forecasting mode.
- Analyze simulation results and evaluate prediction accuracy by comparing simulated concentrations and PB impacts, respectively, with observed concentrations and inferred impacts, by comparison to nearby monitors that are not impacted.
- Perform diagnostic evaluations to understand if agreement between simulation and observations is because of the right reasons and, in case of disagreement, to determine ways of improving the forecasting methods.

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Investigation and Assessment of Management Options

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- We will work with AQ managers at GA EPD and PB managers at GFC to develop a draft protocol for utilizing the PB impact forecasts as a tool to minimize poor AQ and maximize PB activity.
- We will assess the differences between PB permit decisions made with and without the new information (i.e. air quality and impact forecast).
  - This will be done for incidence day as well as good AQ days.
  - PB emissions will be estimated using both sets of decision and AQ will be simulated.
  - The difference in simulated air quality levels will be attributed to utilizing the impact prediction system.
  - The change in burn capacity will also be assessed.

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Overall Project Plan

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Task	Year-1				Year-2				Year-3			
1) Development of PB Impact Forecasting system												
2) Evaluation of PB Impact Forecasting System												
3) Investigation and Assessment of Management Options												

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Expected Results & Outcomes

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- Increased accuracy of air quality forecasts: Missed exceedances because of PB impacts will be avoided
- Ability to manage burning in real time while accounting for predicted impacts on air quality
- Ability to develop best-practice burning protocols
- Ability to quantify the benefit of dynamic PB management on air quality
- Guidance on how much PB can be done on each day for each county